

July 11, 1944.

P. F. G. HOLST ET AL

2,353,468

FREQUENCY MODULATION RECEIVER CIRCUIT

Filed May 22, 1942

2 Sheets-Sheet 1

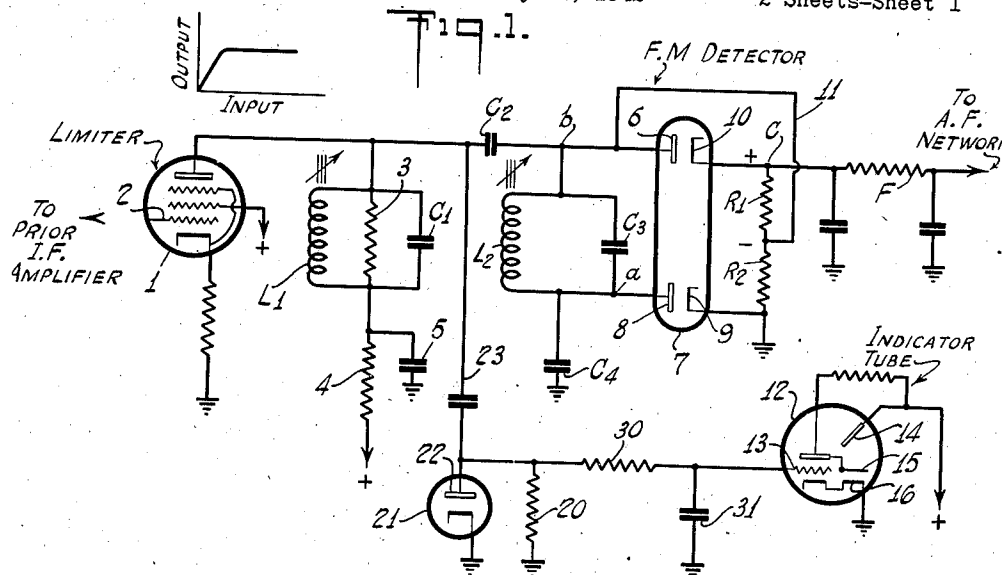
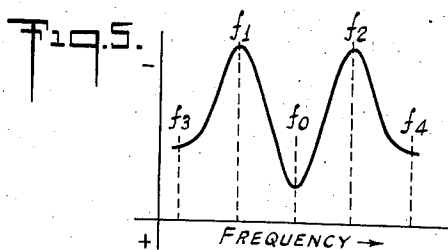
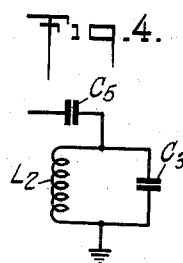
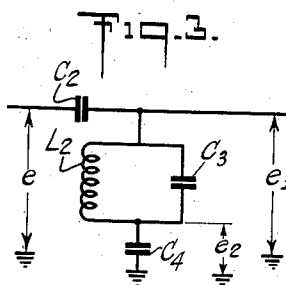
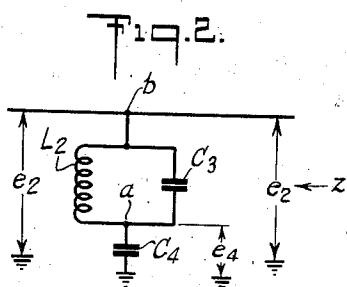
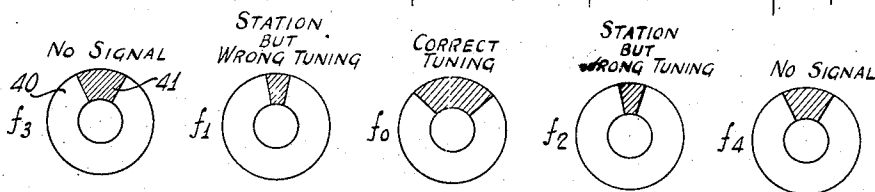


Fig. 1a. Fig. 1b. Fig. 1c. Fig. 1d. Fig. 1e.



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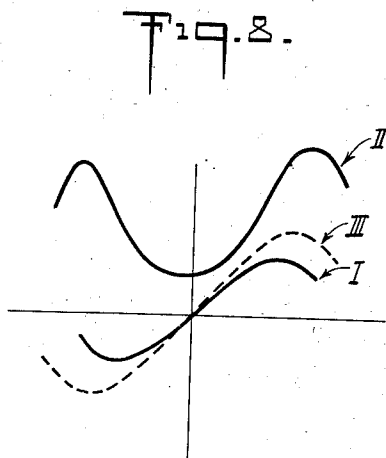
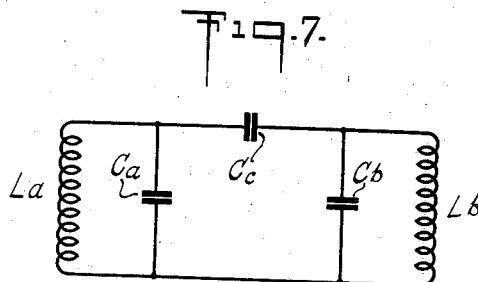
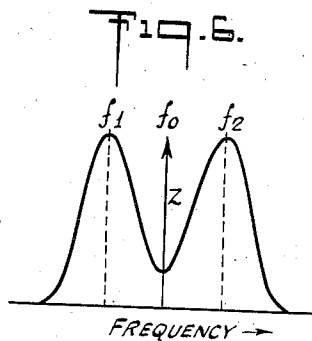
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2 Sheets-Sheet 2



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2,353,468

FREQUENCY MODULATION RECEIVER
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8 Claims. (Cl. 250—27)

Our present invention relates generally to detectors of angular velocity-modulated carrier waves, and more particularly to a detector of frequency modulated carrier waves.

One of the main objects of our invention is to provide in a simplified type of detector of angular velocity-modulated carrier waves networks whose constants are so related as to provide optimum and efficient performance.

Another important object of our invention is to provide a frequency modulation detector circuit of simplified and efficient construction with which is associated a visual indicator circuit which is capable of indicating correct tuning of the receiver; incorrect tuning; and no-signal state.

Another important object of this invention is to provide a simplified form of frequency modulation detector circuit of the type employing opposed rectifiers having a resonant circuit employing only one inductive element as the input circuit thereof, the latter being fed with signal energy from the resonant output circuit of a prior signal transmission tube; and a visual indicator tube being energized from a point intermediate the aforesaid resonant circuits.

Still other objects of our invention are to provide a highly efficient and simplified type of frequency modulation detector circuit, and indicator therefor, in an economically manufacturable form.

The novel features which we believe to be characteristic of our invention are set forth with particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawings in which we have indicated diagrammatically a circuit organization whereby our invention may be carried into effect.

In the drawings:

Fig. 1 shows a circuit embodying the invention,

Figs. 1a to 1e inclusive each show the appearance of the indicator tube target for different conditions of resonance of the receiver,

Figs. 2, 3 and 4 respectively show different circuit considerations in analyzing the construction of the resonant input circuit of the detector,

Fig. 5 shows the characteristic of the indicator control voltage,

Fig. 6 illustrates the pass-band characteristic of the detector input circuit,

Fig. 7 illustrates a circuit used for analysis,

Fig. 8 graphically shows various characteristics relating to the detector input circuit.

Referring now to the accompanying drawings, wherein like reference characters in the different figures designate similar circuit elements,

there is shown in Fig. 1 that portion of a frequency modulation receiver which is located between the limiter input circuit and the input electrodes of the audio frequency amplifier. Those skilled in the art are fully acquainted with the general construction of receivers designed for the reception of frequency modulated carrier waves (FM) as employed in the assigned FM broadcast band of 42–50 megacycles (mc.). Each station channel in this band has a maximum deviation range of 100 kilocycles (kc.) on each side of the center frequency, although at each FM transmitter the carrier actually is deviated to a maximum of 75 kc. on either side of the center, or mid-band, frequency. At the transmitter the carrier is deviated in accordance with the amplitude of the modulation signals; the rate of deviation is a function of the modulation frequencies per se. The term "angular velocity-modulated carrier waves" is generic and is employed in this specification to designate either frequency modulated, or phase modulated, carrier waves.

The FM receiver is usually of the superheterodyne type, and comprises the usual signal collector which feeds one or more ultra-high frequency amplifiers each tuned to the center frequency of the desired FM station. The FM signal energy is fed to a first detector, which is supplied with local oscillations from a tunable oscillator so that the FM signal energy can have its center frequency reduced to a desired intermediate frequency (IF). While the operating IF value may be chosen from a wide range of values, an IF value of 4.3 mc. has been chosen. It will be understood, of course, that even though the center frequency of the FM energy has been reduced to the IF value, the range of frequency deviation is the same as in the original signal wave. Hence, the various IF amplifier stages each must be designed to have a pass-band in excess of 150 kc., so as to pass the maximum permissible frequency swings of the signal energy.

In order to prevent amplitude variations in the carrier from affecting the performance of the demodulator, there is usually employed a limiter network which functions to prevent any amplitude effects in the FM signals from getting through to the detector. Since at the transmitter the carrier is swung in frequency in accordance with the modulation signals, it is desired to have the detector responsive solely to frequency deviation at the detector input circuit. The limiter network may be of any desired and well known type. In Fig. 1 it is shown as an electron discharge tube 1, upon whose input electrode 2 is applied the IF energy. The limiter has its grid bias, plate voltage and input circuit constants so chosen that the output increases with increasing input up to a predetermined input amplitude

point. Thereafter, the output is substantially flat in the manner shown graphically above tube 1.

The plate circuit of tube 1 includes a resonant primary circuit comprising coil L_1 and condenser C_1 in parallel. A resistor 3 is connected in shunt with the reactive elements of the resonant circuit. The purpose of the resistor 3 is to provide sufficient damping so that the required pass-band characteristic is secured. The low potential side of resonant circuit L_1-C_1 is connected to the plate potential source through voltage reducing resistor 4 whose upper end is by-passed to ground by condenser 5.

The high potential side of the resonant circuit L_1-C_1 is connected by condenser C_2 to the anode 6 of the double diode rectifier 7. While separate diodes may be used, it is preferred to employ a double diode tube of the 6H6 type. The anode 6 and the condenser C_2 are connected in common to the high potential side of the parallel resonant secondary circuit L_2-C_3 . The coils L_1 and L_2 may have adjustable iron cores, as shown. The anode 8 of the second diode of tube 7 is connected to the low potential side of resonant circuit L_2-C_3 , and the low potential side of that circuit is connected to ground through condenser C_4 . The cathode 9 associated with anode 8 is connected to the grounded end of the detector load resistor, while the cathode 10 associated with diode anode 6 is connected to the upper end of the load resistor. The midpoint of the load resistor is connected by lead 11 to the anode 6, and the load resistor is thus divided into two resistive sections R_1 and R_2 . If desired, the lead 11 can be made from the midpoint of the resistor load to the anode 8. The audio voltage developed across the load resistor of the detector is transmitted to one or more stages of audio amplification. The filter F prevents any I. F. components from being transmitted to the audio utilization network.

It will be explained at a later point how the network between tube 1 and tube 7 is designed to provide efficient and optimum performance. It is sufficient for the present purposes to point out that the detector functions to develop across load resistor R_1-R_2 in series the modulation signal voltage corresponding to the same modulating signal voltage utilized at the transmitter. To inform the operator of the receiver that he has accurately tuned to the center, or mid-band, frequency of the desired FM station, there is provided a tuning indicator tube of the fluorescent target type. The numeral 12 denotes such an indicator tube. For example, a tube of the 6E5 type may be employed for the tube 12. As those skilled in the art fully know, such a tube comprises a direct current voltage amplifier section upon whose input grid 13 may be applied control voltage.

The numeral 14 schematically denotes the fluorescent target employed in such a tube. The numeral 15 denotes the electron control electrode which controls the emission of electrons from cathode 16 to the target 14. The deflecting electrode 15 is variable in potential in the same manner as the voltage of the plate circuit in the voltage amplifier section. Attention is directed to U. S. Patent No. 2,051,189 granted August 18, 1936, to H. M. Wagner for a disclosure of an indicator tube which can be employed as the tube 12. It is sufficient for the purpose of this application to point out that control voltage for grid 13 may be derived from across a load resistor 20 which is arranged between the anode and the cathode of diode rectifier 21. The diode anode 22 is con-

nected by a direct current blocking capacitor and lead 23 to the left hand terminal of condenser C_2 , while the diode cathode is grounded.

It will, therefore, be seen that the diode 21 functions to rectify the signal energy developed across resonant circuit L_1-C_1 . The magnitude of the rectified voltage will be directly proportional to the I. F. signal voltage appearing across the resonant circuit L_1-C_1 . For a usable signal input to the antenna connection of the receiver, the signal across the resonant circuit L_1-C_1 will be a function of the receiver tuning, and will vary as shown in Fig. 5. In the latter f_0 represents correct tuning, while f_1 and f_2 represent tuning condition of the receiver to respectively lower and higher values than the correct tuning frequency. The means by which this characteristic is obtained will be explained fully later in this specification.

If the receiver selector circuits are adjusted to either side of center frequency f_0 the voltage across resistor 20 will have a magnitude which differs from its value when the selector circuits are accurately adjusted to the center frequency of the FM station. The control grid 13 is connected through filter resistor 30 to the anode end of resistor 20, the condenser 31 being connected from the grid end of the resistor 30 to ground. The network 30-31 functions as a filter for alternating currents and voltages so that grid 13 will vary solely in accordance with direct current voltage variation.

Figs. 1a-1e inclusive show respectively different appearances of the fluorescent target of the indicator tube as the operator tunes from one side of exact resonance to the other side through the center frequency. It will be understood that the non-shaded area 40 is the fluorescent area upon which electrons from cathode 16 impinge upon target 14. The numeral 41 indicates the shaded area which represents that portion of the target which does not receive any electrons because the deflection voltage on electrode 15 is positive and therefore will attract electrons. In other words, area 41 is the electron shadow of deflection electrode 15 when the latter has a positive potential.

The width of the shadow will depend on the value of the positive voltage on the deflection element 15 in such a manner that the greater the positive voltage the less is the shadow width; and conversely the smaller the positive voltage of element 15 the greater is the width of the shadow. As is well known, a greater negative voltage on the control grid 13 will produce a less positive voltage on the anode, and therefore a less positive voltage on the deflection electrode 15. Conversely a smaller negative voltage on the control grid 13 will produce a more positive potential on the anode and a more positive voltage on deflection element 15. From Fig. 5 it is, therefore, evident that the shadow width will vary with tuning as indicated on Figs. 1a to 1e inclusive, corresponding to the response at the tuning frequencies $f_3-f_1-f_0-f_2-f_4$ as indicated in Fig. 5. In particular it should be noted that the shadow will have its maximum width at the point of correct tuning, and consequently the indicator circuit described here will enable an operator to determine when the receiver is tuned to the center frequency of an angular velocity modulated signal.

There will now be considered the manner in which the detector input network should be designed to provide optimum and efficient operation. It is desired in the design of FM receivers

that the detector circuit satisfy the following requirements:

(1) It should be of the balanced type to obtain a reduction in noise, and insensitivity to amplitude modulation.

(2) The response characteristic must be reasonably linear within the working range of the system to obtain a low distortion.

(3) The linearity should be an inherent characteristic. That is, it should not be the result of two complementary nonlinear characteristics, since complementary circuits are subject to excessive change from normal slight circuit constant changes.

(4) It should possess a slope sensitivity high enough to overload an audio amplifier of average gain with frequency deviations equivalent to less than 10% modulation.

(5) Stability should be maintained with fairly large temperature changes.

(6) The frequency detector should be of economical design, and easy to adjust in production.

With these requirements in mind the performance of the detector circuit shown in Fig. 1 will be analyzed. Assume that there exists an I. F. voltage between the point *a* and ground. This voltage will be rectified by diode 8—9 in a manner which will cause a negative voltage to exist across the resistor *R*₂. This same negative voltage will be impressed on both the cathode and anode of diode 6—10. This latter diode will detect the I. F. voltage between *b* and ground so that the voltage across *R*₁ will be positive. The resulting voltage from *c* to ground will be the sum of the two individual voltages, and it may be positive, negative or zero depending on the value of the rectified voltages.

Next consider the circuit between *b* and ground. The performance of this circuit may be analyzed as follows (see Fig. 2). Two resonances will exist, namely (1) the parallel resonance between *L*₂ and *C*₃ which will cause the circuit to provide a high impedance *Z* between *b* and ground, and (2) the series resonance of *L*₂—*C*₃ in conjunction with *C*₄, which will cause the circuit to provide a low impedance *Z* between *b* and ground. We are principally interested in the following three frequencies:

- (a) The frequency at which the series resonance occurs ----- *f*_s
- (b) The frequency at which the parallel resonance occurs ----- *f*_p
- (c) The frequency for which *e*₂=*e*₄ ----- *f*₀

For this latter frequency *f*₀ the output from the discriminator will be zero.

Mathematically, it can be shown that with good approximation:

$$f_s = \frac{1}{2\pi\sqrt{L_2(C_4 + C_3)}} \quad (1)$$

$$f_p = \frac{1}{2\pi\sqrt{L_2 C_3}} \quad (2)$$

$$f_0 = \frac{1}{2\pi\sqrt{L_2\left(C_3 + \frac{C_4}{2}\right)}} \quad (3)$$

We can, therefore, state with good accuracy that the point (frequency) for which the discriminator has zero output will fall "mid-way" between the two resonances, or that

$$f_0 = \frac{1}{2}(f_s + f_p).$$

Consider next that the circuit shown in Fig. 2

is coupled to a prior network by means of condenser *C*₂. This is shown in Fig. 3. As far as the load on the other circuit *L*₁—*C*₁ is concerned the circuit may be redrawn as shown in Fig. 4.

Here *C*₅ represents the series connected capacitors *C*₂ and *C*₄. Let us next consider that the preceding circuit is another tuned circuit as shown in Fig. 1. Then, as far as the primary performance is concerned the performance is simply that of a capacity-coupled I. F. transformer.

If we desire to line up a transformer of this type, then it is required that the following circuits shall resonate at the center frequency (*f*₀):

$$L_1 \text{ with } (C_1 + C_5) \quad (4)$$

$$L_2 \text{ with } (C_3 + C_5) \quad (5)$$

In order to obtain symmetrical performance of the entire circuit around the center frequency (*f*₀) (which may also be termed the cross-over frequency), then it is required that the aforesaid resonances (4) and (5) should occur at the frequency *f*₀. There has been placed no restrictions on the constants in (4), but (5) must be considered together with Equation 3, which will require that:

$$C_3 + C_5 = C_3 + \frac{C_4}{2}$$

or,

$$C_5 = \frac{C_4}{2}$$

which will be the case if *C*₂=*C*₄. For later use it is noted that if the above requirement is complied with, then the frequency characteristic across the primary circuit *L*₁—*C*₁ will be symmetrical with respect to *f*₀.

If the above condition is fulfilled, the impedance characteristic of the circuit inserted in the anode supply of the limiter tube will be symmetrical with respect to *f*₀, and it may through proper choice of constants be made to appear as shown in Fig. 6. However, if the same characteristic is measured from the antenna circuit it will be modified as indicated in Fig. 5, due to the effects of thermal and other noise on the circuit. It should be noted that the voltage at the center frequency may be made lower than the voltage existing for a completely detuned circuit, which explains the performance of the indicator described previously in this specification.

We will now return to our original problem which was to produce a discriminator characteristic which is linear over the operating range, and symmetrical with respect to the cross-over frequency *f*₀. Let us take the latter requirement. First referring to Fig. 3, we have determined the conditions under which the frequency characteristic of the voltage is symmetrical with respect to *f*₀. For our present purpose we may assume that the voltage *e* is constant; this being one kind of symmetrical response.

For the special case where *L*₂ has no losses the symmetry of the circuit shown in Fig. 3 is easily shown for the case where *C*₂=*C*₄ for the resonance frequencies *f*_p and *f*_s. The resonance frequency *f*_p gives *e*₁=*e*, and *e*₂=0, because the circuit *L*₂—*C*₃ has infinite impedance. The resonance frequency *f*_s gives *e*₁=0, and *e*₂=*e*, because the circuit across which *e*₁ would exist has zero impedance and the voltage across *C*₂ and *C*₄ will, therefore, be equal. Elaborate calculations indicate that the symmetry will hold at all other frequencies.

For the case where loss exists in the coil and the diode adds further losses, it has been found that the circuit will be substantially symmetrical as long as the losses are not excessive. The conclusion drawn from the above is, therefore, that the symmetry of the circuit will be satisfactory. Let us next consider the proper choice of the L/C ratio of the circuits L_1-C_1 and L_2-C_3 . First, assume that both circuits have the same L/C ratio. Calculations in this case indicate that the impedance characteristic of the primary with the secondary connected will be as shown in Fig. 6, and that:

$$f_1 = \frac{1}{2\pi\sqrt{L_2 C_3}}$$

$$f_0 = \frac{1}{2\pi\sqrt{L_2 \left(C_3 + \frac{C_4}{4} \right)}}$$

$$f_2 = \frac{1}{2\pi\sqrt{L_2 (C_3 + C_4)}}$$

It will be noted that these frequencies are the same as those indicated for the secondary in the previous Equations 1, 2 and 3. This condition is not very desirable because it is not possible to adjust the curvatures in a manner which will produce a linear detector characteristic, inasmuch as the curvatures are in general the same and of the character shown in Fig. 6. It is, however, possible to locate the primary and secondary resonances at different frequencies. Assume that the primary and secondary circuits have different L/C ratios, and that the resonances are still adjusted so that:

$$f_0 = \frac{1}{2\pi\sqrt{L_a(C_a + C_c)}} = \frac{1}{2\pi\sqrt{L_b(C_b + C_c)}}$$

These values refer to the analysis circuit of Fig. 7.

We, then, find that the primary resonance peaks will be located at frequencies which are respectively higher and lower than the resonances within the secondary circuit. That is, the primary peaks will have a greater separation if the L/C ratio of the primary is higher than the L/C ratio of the secondary. The effect of these relations may be visualized by reference to Fig. 8. Let curve I represent the discriminator curve as it would be if a flat voltage characteristic is presented to condenser C_2 in Fig. 3. Curve II represents a characteristic of the primary where the peaks are farther apart. The combined dotted curve III will then be seen to be "flatter" over a greater frequency range and to possess greater sensitivity. The primary loading resistor 3 may be used as a convenient means to adjust the "flatness" of the discriminator curve, because it controls the primary peaks.

The following purely illustrative constants have been found satisfactory:

Example 1	Example 2
$C_1 = 150$ microfarads (mf.)	100 mf.
$C_3 = 270$ microfarads (mf.)	170 mf.
$C_2 = 33$ micro-microfarads (mmf.)	18 mmf.
$C_4 = 33$ mmf.	18 mmf.
$C_5 = 0.01$ mf.	0.01 mf.
$R_3 = 5,600$ ohms	10,000 ohms
$R_1 = R_2 = 100,000$ ohms	150,000 ohms

While we have indicated and described several systems for carrying our invention into effect, it will be apparent to one skilled in the art that our invention is by no means limited to the particular organizations shown and described, but

that many modifications may be made without departing from the scope of our invention, as set forth in the appended claims.

What we claim is:

1. In a detector of angular velocity-modulated carrier waves, a pair of rectifiers, a source of such waves, a first resonant circuit, a second resonant circuit, means connecting the opposite sides of the second circuit to a respective one anode of said rectifiers, means capacitatively coupling the high potential sides of said two circuits, means capacitatively connecting the low potential side of the second resonant circuit to a point of relatively fixed alternating potential, an output load connecting the cathodes of said rectifiers, means establishing a point on said load at a relatively fixed alternating potential, means for deriving modulation voltage from another point on said load, the L/C ratio of the two resonant circuits being different, and the constants of the network between said source and said rectifiers being so chosen that the resonance peaks of the response curve of one resonant circuit are of greater separation than the resonance peaks of the other resonant circuit.

2. In a frequency modulation detector of the type comprising a pair of diode rectifiers, a resonant primary circuit, a resonant secondary circuit, means coupling the opposite sides of the secondary circuit to respective anodes of the diodes, means capacitatively coupling the high potential sides of the primary and secondary circuits, means capacitatively coupling the low potential side of the secondary circuit to ground, an output resistor connecting the diode cathodes; the improvement which comprises said primary circuit having a higher L/C ratio than the L/C ratio of said secondary circuit whereby the primary resonance peaks have a greater separation than the secondary resonance peaks.

3. In a detector of the type defined in claim 2, a visual current indicator tube of the fluorescent target type, a rectifier other than said diode rectifiers coupled to said primary circuit, and means responsive to the rectified voltage output of the latter rectifier for controlling the indications of said indicator tube.

4. In a detector of the type defined in claim 1, a rectifier other than said pair of rectifiers coupled to said first resonant circuit, a tuning indicator tube, and means responsive to the rectified output of the last named rectifier for controlling the indicator tube.

5. In a detector of angular velocity modulated waves, a source of said waves, a discriminator circuit comprising a primary circuit and a secondary circuit coupled thereto, said primary circuit having its constants so chosen that its frequency response characteristic has a pair of widely spaced peaks located on either side of the mean frequency of said waves and a minimum response at said mean frequency, a rectifier coupled to the primary circuit, said rectifier rectifying minimum response voltage at said mean frequency to indicate correct tuning, and an indicator indicating the rectified voltage.

6. In a demodulator of frequency modulated carrier waves, a pair of diode detectors, a source of such waves, a first resonant circuit, a second resonant circuit, means connecting the opposite sides of the second circuit to a respective one anode of said diodes, a condenser coupling the high potential sides of said two circuits, a condenser connecting the low potential side of the

second resonant circuit to a point of relatively fixed alternating potential, an output load resistor connecting the cathodes of said diodes, means establishing a point on said load at a relatively fixed alternating potential, means for deriving modulation voltage from another point on said load, the L/C ratio of the two resonant circuits being different, and the constants of the network between said source and said diodes being chosen to render the resonance peaks of the response curve of one resonant circuit of greater separation than the resonance peaks of the other resonant circuit.

7. In a frequency modulation detector of the type comprising a pair of diode rectifiers, a resonant primary circuit, a resonant secondary circuit, means coupling the opposite sides of the secondary circuit to respective anodes of the diodes, means capacitatively coupling the high potential sides of the primary and secondary circuits, means capacitatively coupling the low potential side of the secondary circuit to ground, an output resistor connecting the diode cathodes; the improvement which comprises said primary circuit having a higher L/C ratio than the L/C ratio of said secondary circuit, an indicator tube

of the fluorescent target type, a third rectifier coupled to solely said primary circuit, and means responsive to the rectified voltage output of solely the third rectifier, for controlling the indications of said indicator tube.

8. In a frequency modulation detector of the type comprising a pair of diode rectifiers, a resonant primary circuit, a resonant secondary circuit, means coupling the opposite sides of the secondary circuit to respective anodes of the diodes, means capacitatively coupling the high potential sides of the primary and secondary circuits, means capacitatively coupling the low potential side of the secondary circuit to ground, an output load connecting the diode cathodes; the improvement which comprises said primary circuit having a higher L/C ratio than the L/C ratio of said secondary circuit whereby the primary resonance peaks have a greater separation than the secondary resonance peaks, a diode coupled to said primary resonant circuit, an indicator tube, and means responsive to the rectified output of the last named diode for controlling the indicator tube.

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